

Integrated Optics in Films of Organic and Polymeric Materials

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In recent years, a great deal of interest has been directed toward the use of organic materials in the development of high-efficiency optoelectronic and photonic devices. There is a myriad of possibilities among organics which allow flexibility in the design of unique structures with a variety of functional groups. The use of nonlinear optical (NLO) organic materials as thin film waveguides allows full exploitation of their desirable qualities by permitting long-interaction lengths and large susceptibilities allowing modest power input. Organics have many features that make them desirable for use in optical devices such as high-second and third-order nonlinearities, flexibility of molecular design, and damage resistance to optical radiation. However, their use in devices has been hindered by processing difficulties for crystals and thin films.

Here, we report research and technology progress relevant to photonic applications of phthalocyanines (Pc) and the potential role of microgravity on processing these materials. It is of interest to note how materials with second- and third-order nonlinear optical behavior may be improved in a diffusion-limited environment and ways in which convection may be detrimental to these materials. In this report, we focus our discussion on third-order materials for all-optical switching.

Materials processing techniques of general interest are solution-based and physical vapor transport (PVT), both having proven gravitational acceleration dependence. Two promising classes of organic compounds for optical thin films and waveguides are polydiacetylenes, which are conjugated zig-zag polymers, and phthalocyanines, which

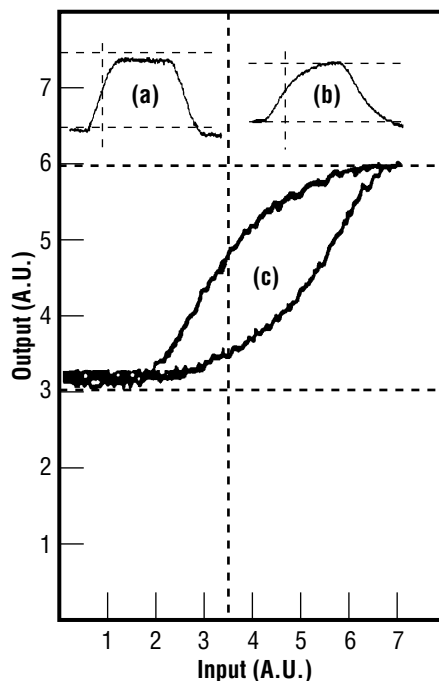


FIGURE 142.—The bistability loop of a 833 nm metal-free phthalocyanine film using a chopped CW He-Ne laser at 632.8 nm: a) the input pulse; b) the transmitted pulse; c) hysteresis switching constructed from (b).

are large ring-structured porphyrins. Epitaxial growth on ordered organic and inorganic substrates under various processing conditions have been useful for preparing highly oriented polydiacetylene (PDA) and phthalocyanine films. The degree of significance relating processing conditions to uniformity in thickness, degree of orientation, and optical properties for a specific processing technique is the general focus of work in this area. It is a goal of some researchers to produce good quality anisotropic films, therefore, an important yet understudied requirement should be to assess the role of gravity during processing. This may be particularly true for the vapor deposition of Pc's in view of the results of microgravity experiments by 3M Corporation involving the

preparation of thin films of copper Pc (CuPc). Microgravity grown CuPc had several desirable features which indicate that the growth of organic films in low-g may result in better quality films for optical and electrical applications. Important aspects of any study involving fluids, as in vapor transport, are driving mechanisms for heat transfer with natural convection and diffusion processes which determine flow profiles and temperature distributions. In terms of processing by PVT, phthalocyanines are excellent nonlinear optical materials with the promise of significantly improved NLO properties through order and film quality enhancements possible by microgravity processing. Although fibers have dramatically increased node to node network speeds, electronic switching will limit network speeds to about 50 Gb/sec. Already, it is apparent that terabit-rate speeds will soon be needed to accommodate the 10- to 15-percent/month growth rate of the Internet and the increasing demand for bandwidth intensive data such as digital video.

Primarily, the study of this work focuses on important technologies, particularly involving thin films, relevant to organic and polymeric materials for improving applicability to optical circuitry and devices and to assess the contribution of convection on film quality in unit and microgravity environments. All-optical switching using nonlinear optical materials can relieve the escalating problem of bandwidth limitations imposed by electronics. Several important limitations need to be overcome such as the need for high- χ^3 materials with fast response and minimum absorption (both linear and nonlinear), development of compact laser sources, and reduction of the switching energy.

Investigation of the bistability of metal-free Pc films of 833-nm thickness used a chopped He-Ne 632.8-nm laser beam at frequencies ranging from 100 to 750 Hz. The film was positioned on a micrometer stage, at the lens focus, and transversely translated in and out of the beam alternately to record intensity input (fig. 142 (a)) and

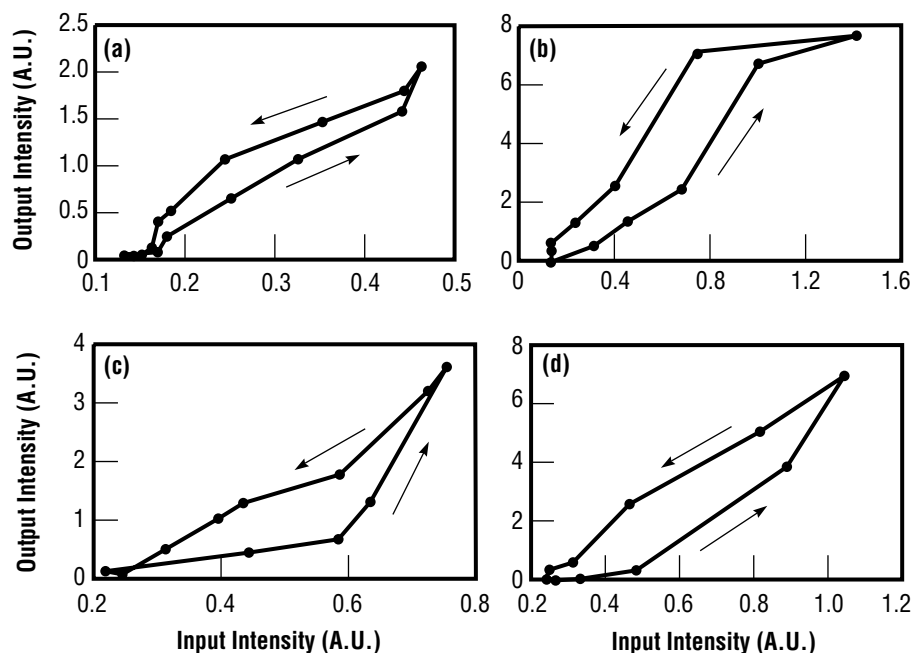


FIGURE 143.—The bistability loop for different time spans of a metal-free phthalocyanine film of thickness 232.5 nm using a CW He-Ne laser. Time spans between successive points are: a) 3.84 sec; b) 10 sec; c) 342 sec; d) 1800 sec. (a) shows the least prominent bistability loop, while (b), (c), and (d) show a minimal effect of the time span between points.

film transmittance (fig. 142 (b)). A digitizing oscilloscope recorded the input and the transmitted pulse. The nonsymmetrical shape of the transmitted pulses indicated the presence of intrinsic bistability in metal-free phthalocyanine. Figure 142 (c) depicts typical bistable switching, constructed from the transmitted pulse. The switching power of ~ 0.33 mW per pulse in combination with a pulse duration of 1.37-ms recovery time yields a very low switching energy of ~ 0.45 nJ. Observation of bistability was repetitive in the same film using a CW He-Ne laser as shown in figure 143b for different time spans between successive points. Source and substrate temperatures were maintained at 300°C and 5°C , respectively, while vapor vacuum deposition, in this case, occurred at 10^{-6} torr onto quartz disks.

One result of this work is the determination, theoretically, that buoyancy driven

convection occurs at low pressures (determination at 10^{-2} mm) in an ideal gas in a thermal gradient from source to sink. Subsequent experiment supports the theory. A further result of this work is the discovery of intrinsic optical bistability in metal-free phthalocyanine films which enables the possibility of the development of logic gate technology on the basis of these materials. Bistability in these films is due to changes in the level of absorption and refractive index caused by thermal excitation. This nonlinear effect could improve dramatically in highly oriented microgravity processed films.²

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